East Clayton Stormwater Infiltration Systems Design and Predicted Operation

J. Dumont
McElhanney Consulting Services Ltd.

Abstract
The East Clayton Neighbourhood Concept Plan includes land use and planning concepts, development guidelines as well as servicing and financing plans for a new 250-hectare neighbourhood within the City of Surrey. The Plan calls for the use of innovative storm water management. The Plan is a policy framework with specific performance targets to guide the development of this sustainable community. The City of Surrey has partnered with senior government agencies and developers in building a large pilot development.

The Plan calls for stormwater infiltration systems to maintain the hydrologic regime in its predevelopment form. This requires the use of stormwater infiltration systems to match the runoff pre-development and post-development hydrographs. Designing these systems required innovative techniques to predict and optimize their performance in some very difficult terrain with high groundwater and low infiltration rates.

The infiltration systems designed using conventional techniques, using individual design storms resulted in very promising results. The operational characteristics were then tested using continuous simulations using long-term, multiple year (1962 through 1998) rainfall records. Several modifications were required to optimize the systems while identifying performance limitations. The first phase of development has been constructed and the operation of the stormwater systems will be monitored to verify their performance.

Introduction
The City of Surrey has partnered with senior government agencies and developers in building a large pilot development in the East Clayton NCP Area in Surrey, see Figure 1. The East Clayton area is an approximately 250-hectare (617-acre) area located on the southeastern edge of the larger Clayton district, an approximately 909-hectare (2,250-acre) area on the Surrey/Langley border. The average single family lot in this development will occupy approximately 320 m^2 and will have an imperviousness of 65%. The overall imperviousness of the development, with open green areas, single family and multifamily housing will be from 65% to 75%.

A guiding principal proposed by the Province of British Columbia indicates that stormwater management strategies for urban developments should strive to mimic the Natural Water Balance. Therefore, the proposed infiltration systems should be designed using the following criteria:

- Match the predevelopment volumetric runoff rates.
- Match the predevelopment discharge duration relationships.

The provincial guidebook indicates that storms can be described using three tiers or levels based upon rainfall volume for a 24-hour day. Tier 'A' is less than 50% of a Mean Annual Storm (MAS), is the source of 74% of all rainfall volume, and has a volume of approximately 30 mm. Tier 'B' storms are larger that Tier 'A' but not greater than a mean annual storm. Tier 'B' represent 24% of all rainfall volume with a volume of 60 mm. Tier 'C' storms are larger than the MAS and have 2% of all rainfall volume. This represents an analysis of daily rainfall amounts and may not accurately reflect actual total storm volumes when multiple day events occur.

The guidebook offers a simple concept for meeting the guiding principles of stormwater management. The design of stormwater management facilities should store and infiltrate a Tier 'A' storm event. The runoff from Tier 'B' storms should be captured then infiltrated and /or released in a controlled manner. Runoff from Tier 'C' storms should be conveyed safely to a stream.

The infiltration systems within the first phase of development have been designed to meet or to exceed the goals of the guiding principles of stormwater management. Hydrologic and hydraulic simulations were used to test the theoretical operation of the systems. The design and assessment of on-lot stormwater infiltration systems was intended to establish criteria for application of the systems.

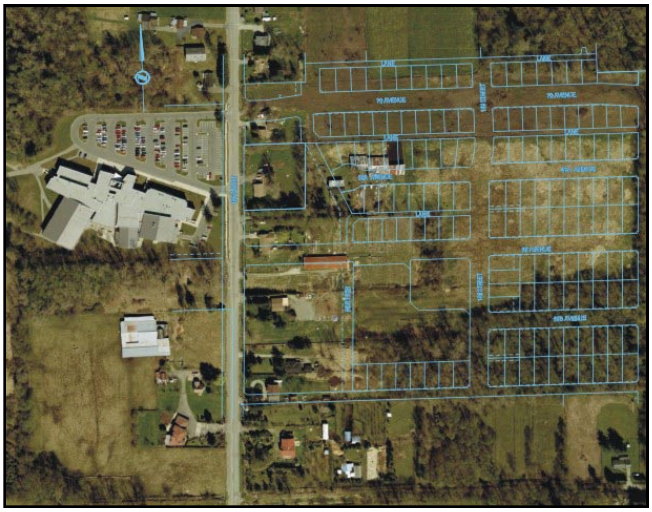

Figure 1. East Clayton, Phase 1.

Assessment

The infiltration systems were designed using conventional techniques with individual design storms. The results of the analyses were very promising. The operational characteristics were then tested using continuous simulations using long-term, multiple year (1962 through 1998) rainfall records. Several performance limitations were identified, resulting in modifications to optimize the system operation.

The methodologies developed as part of this paper address the impacts of development upon the volume of runoff and the duration of runoff from the catchment. Separate analysis techniques have been applied to the assessment of the impacts of the single-family development with roof leader disconnection and of the multi-family developments where roof leaders are directly connected.

Design Storm Methodology

The runoff from the single family private lots within the development has been estimated using design storms of one half (½) the Mean Annual Rainfall (0.5MAR) and the Mean Annual Rainfall (MAR). Runoff for houses with roof leaders connected was assessed as well as the disconnected alternative where splash pads would disperse runoff across the permeable fraction of the property. The rainfall and runoff totals for the analyses of the single-family properties are shown in Table 1.

Table 1. Depth Equivalent Rainfall and Runoff

Storm Event	Rainfall	Runoff	
		Connected	Disconnected
MAS	60 mm	39.0 mm	14.4 mm
0.5MAS	30 mm	19.5 mm	3.5 mm

The building requirements in the City of Surrey mandate the disconnection of roof leaders. This requirement brings the development closer to meeting the stormwater management objectives. The runoff from the Tier 'A' storm (3.5 mm or 1.1 m^3) would need to be infiltrated during the storm through a specially constructed storage / infiltration device. An additional amount, the difference between the Tier 'A' and the Tier 'B' storm (10.9 mm or 3.5 m^3) would be stored for infiltration and /or controlled release following the storm. The design storm methodology can be used to meet the criteria for volume, as listed in the guidebook. The duration of flow and matching of the predevelopment hydrology is not predicted with the design storm methodology. This factor is a serious shortfall for the design storm methodology in addressing the guiding principles of stormwater management in British Columbia.

Continuous Simulation Methodology

The results of the design storm methodology did not address the duration of discharge or matching of pre- to- post development hydrographs. As a result, an alternative methodology was developed to assess the operation of the infiltration systems. The chosen methodology involves continuous hydrologic and hydraulic simulation. Flow duration analyses can be undertaken to demonstrate the ability of the proposed systems to mimic the natural hydrologic cycle in terms of both the duration and the volume of runoff. A primary benefit of continuous simulation is that the frequency and duration of various conditions. For example, occurrence of a given level of water in the storage component of the infiltration systems depend not only on the rainfall volume and distribution, but also on antecedent conditions such as soil moisture and the existing water level in the facility prior to rainfall commencing. Continuous simulation allows a direct observation of the condition of interest.

Any system that utilizes stormwater storage is extremely sensitive to conditions prior to any actual rainfall event. A period of relatively low intensity of rainfall, but considerable volume of rainfall, may fill, or at least partially fill, the stormwater storage facilities. The system will react quite differently to a significant rainfall event when the stormwater facilities are empty as compared to when they are partially full from previous rainfall/runoff events.

Long-term (1962 to 1998) continuous precipitation records were used to simulate the response of the storm drainage system under different operational conditions, to establish the storage/infiltration facility outflows, the storage capacities, and to test any necessary adjustments. Through such operational studies it is possible to have a better understanding of the drainage system's response to extended wet weather conditions (multiple events) and combined probability (rainfall and antecedent conditions) events, which might induce the storage/infiltration facilities to fill and to overflow.

Typical computer models do not allow for calculations involving runoff from impervious areas to be discharged onto pervious areas, such as where roof downspouts (roof leaders) are disconnected from the storm sewer system and directed to the surface via splash pads. As a result there is a tendency for designers to ignore the rainfall on pervious surfaces. This practice will not provide a valid water balance assessment. Our approach to the problem of analysing downspout disconnection is to delete the impervious area and to increase the rainfall to the pervious areas to maintain volumetric continuity and to mimic the operation of a catchment where the impervious runoff is directed onto the pervious area. We simply replaced the impervious area with rainfall onto the pervious area. This very simple approach assumes a uniform distribution of rainfall over the pervious area equal to the total volume of rainfall over the entire area. Thus, the hydrologic operation of the entire catchment can be evaluated while maintaining a mass water balance for the purposes of analysis and assessment.

The modeling methodology evaluated the impacts to the complete water balance resulting from urban development as compared to undeveloped conditions. This is particularly emphasized when the results of the discharge duration are combined with the volumetric runoff coefficients for the area. Without an evaluation of both the volumes AND the durations of runoff there can be no direct assumption as to the benefits that the facilities will have upon stream health.

The first part of the analysis determined the volumetric runoff rate and the duration of runoff for predevelopment and post development conditions, assuming no infiltration systems. These conditions form the starting point in defining the catchment hydrology and the required operation of the infiltration systems. The volumetric runoff coefficient is simply the ratio of total runoff volume to the total rainfall volume over the catchment and can be expressed as either a ratio or as a percentage. The predevelopment runoff coefficient is 30.4% and the post development coefficient for disconnected areas is 42.1%. To meet the first guiding principle, that of matching runoff volumes, an infiltration system would need to reduce the post development runoff coefficient by 11.7%. This is simplistic and does not consider the flow duration that would be affected by development. Therefore the second criteria regarding flow duration must also be considered.

The flow duration for both the predevelopment and the post development state, without infiltration systems, can be seen on Figure 2. This represents the impacts of development upon the hydrologic response of the area. The post development curve reflects the effect of roof leader disconnection. The duration of the analysis was from 1962 through 1998 inclusive, a total of 37 years or 324,400 hours. As can be seen there is a considerable increase in the duration of discharge over the entire range of discharges.

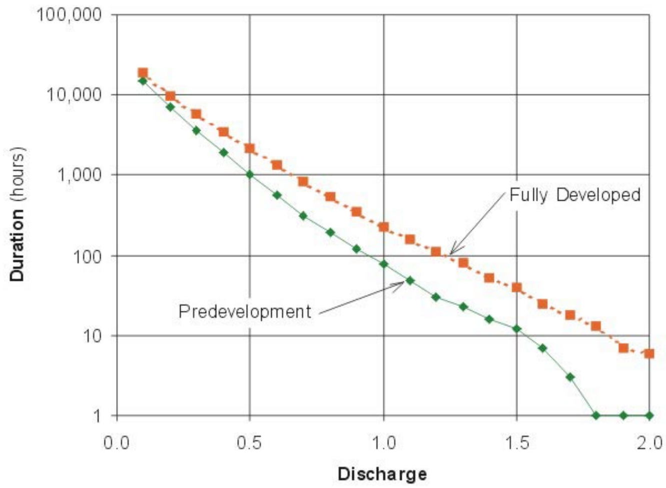

Figure 2. Hydrologic Impacts.

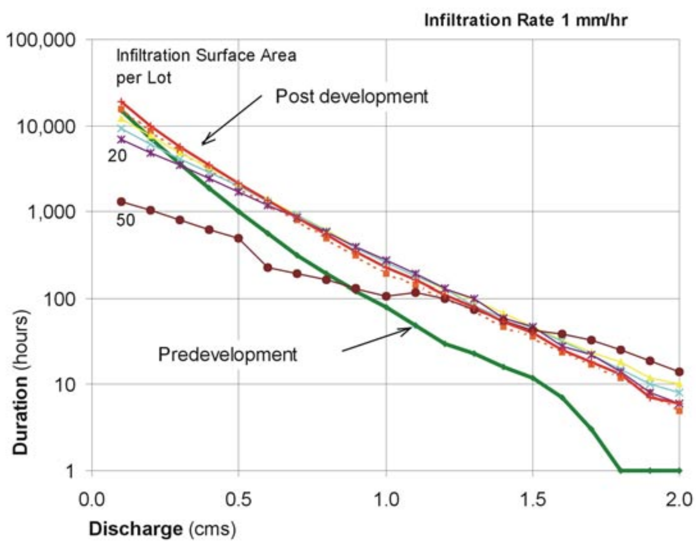

Figure 3. Typical Installation

The typical infiltration facility will be fully contained on private property. A typical plan view of a single-family lot with the facility is shown on Figure 3. As can be seen there are limited opportunities to install the infiltration system. The main component is located in the front yard. There will be a pipe to convey runoff from the rear yard to the front as a continuous overland flow path will not be practical between the closely spaces houses.

The lawn drain will serve as an observation point, a clean-out point and a drain for surface runoff. Runoff will be directed into the infiltration trench where it will be stored until it has infiltrated into the ground or it overtops the standpipe in the lawn basin and flows into the off-site storm sewer system. The foundation drains would connect downstream of the flow control (overflow) and thus the foundations and basements would not be flooded by the runoff stored in the infiltration system.

Analyses were undertaken for a range of potential infiltration rates that are representative of those found in Phase 1. The potential infiltration rates range from a low of nearly 0 mm per hour (effectively no infiltration capacity) to a high of approximately 3 mm per hour. The system will include disconnected downspouts and will utilize the maximum available surface infiltration. The infiltration systems will collect runoff from the surface and will allow the maximum infiltration

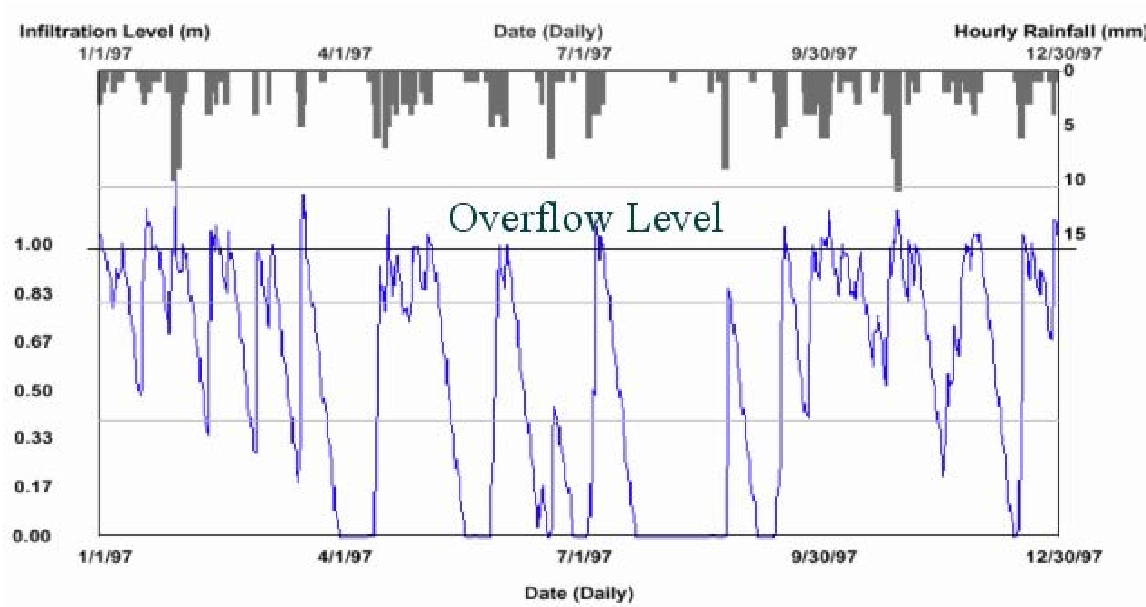

Figure 4. Depth Duration Data.

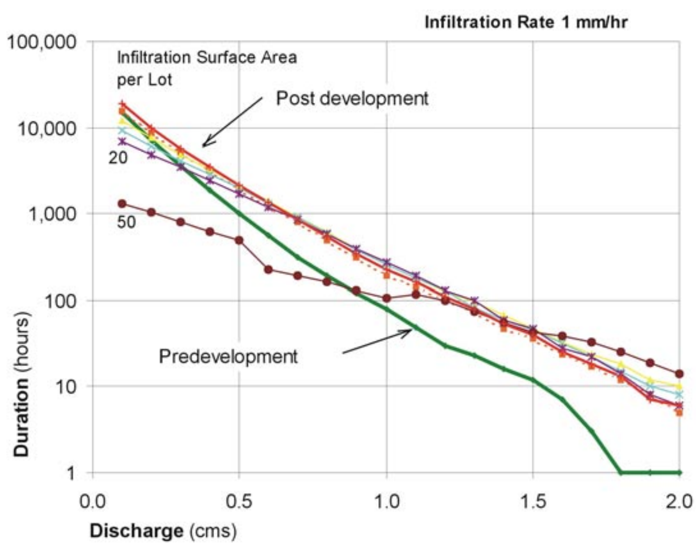

Figure 5. System Operation.

prior to overflowing to the storm sewer system. There would be runoff discharged to the storm sewer only if the storage capacity of the infiltration is full and more rain fell.

System Operation

The utilization, or the depth of water in storage over time, is shown on Figure 4. This system has an infiltration rate of 1 mm/hr and an overflow when the storage capacity is exceeded. In this case the time period is one year, as indicated the year is 1997. As can be seen the storage fills quickly in response to nearly every rainfall / runoff event. The events with long duration occur with significant regularity, as does the high level in the storage and system overflow. This leads to substantial volume of overflow and discharge duration even though the rainfall intensity is relatively low. This chart shows the need to view the system operation over many days to determine the system operation and performance.

The flow duration summary is shown on Figure 5 for the range of infiltration surface area installations in square meters per lot. As can be seen there is little difference in performance for the size ranges from 5 to 20 square meters and only the 50 square meter installations would provide any substantial reduction in the duration of post development flows.

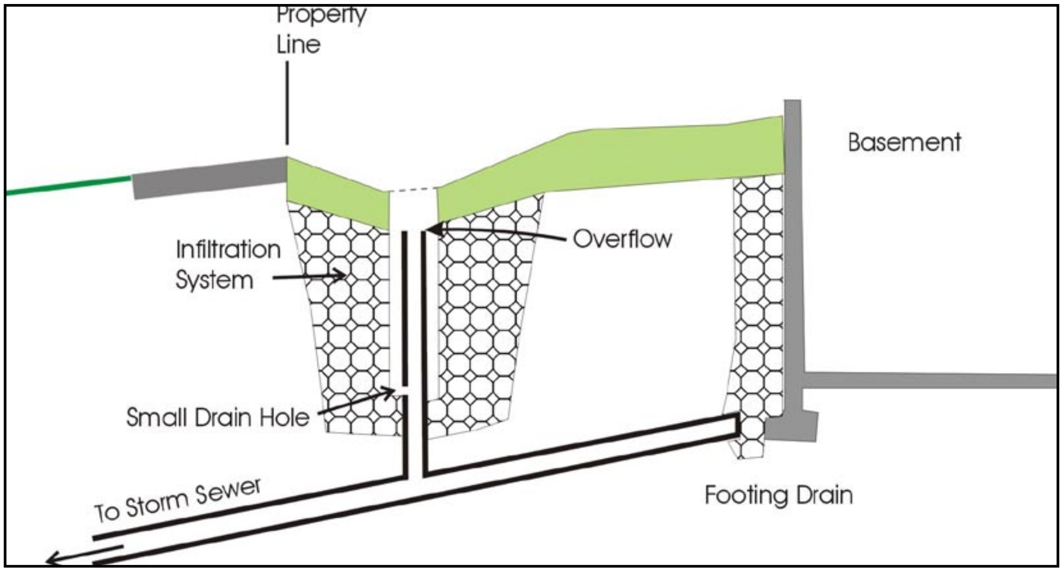

Figure 6. System Modification.

The system configurationas tested has only infiltration and overflow when the storage is full or to dispose of system inflows. As the available storage is frequently full there tends to be a great deal of overflow. This design will decrease the duration of smaller flows to less than predevelopment and will increase the duration of larger flows. This system configuration does not meet the intent of the guidelines.

A further complicating factor is the duration of saturated soil conditions in the vicinity of the infiltration system. Typical vegetation found in residential areas will not tolerate extended periods of root zone saturation. The duration of saturation, which can be seen as the time when the facility would have high water levels, is excessive for most plants.

System Modification

An alternative discharge control system is required to address the anticipated problems for infiltration systems with only a simple overflow. The problems are linked to the duration time that the stormwater storage within the infiltration system is full. To address this problem we propose that a small drain hole be installed in the infiltration overflow pipe to allow the stored runoff to drain out of the system. This would reduce the utilization demands upon the storage and would affect the runoff duration curves. The modified system overflow is shown on Figure 6.

A small 10 mm (less than 1/2 inch) diameter hole in the overflow pipe would allow a limited low flow discharge to augment smaller flows from the catchment. This small hole and the resulting small discharge would allow the storage to empty between rainfall events, thus making room for runoff and would result in a reduction in the discharge duration from the catchment.

The effect of the small hole in the control can be seen on Figure 7. As can be seen this system outflow configuration does much better in matching the predevelopment discharge duration. While the match is not perfect, it is far better than if the small hole in the overflow were not in place. Note that the duration of larger discharges is not affected by the size of the infiltration system storage. Separate discharge reduction facilities will be required for the less frequent but larger runoff causing storm events.

The analysis has, to this point, considered only the duration of discharge criteria. The total runoff coefficient must also be considered. Shown on Figure 8, are the runoff coefficients (Runoff/Rainfall) for the various infiltration system sizes and infiltration rates.

The predevelopment runoff coefficient can be achieved over the range of infiltration rates by varying the size of the infiltration system. That is there would be the same runoff volume from the developed lots as from the undeveloped land. A standard 320 square metre lot with an impervious ratio of 0.65 in an area where the infiltration rate is 1 mm/hr will require a 15 square meter infiltration system with a storage volume of 5 cubic meters.

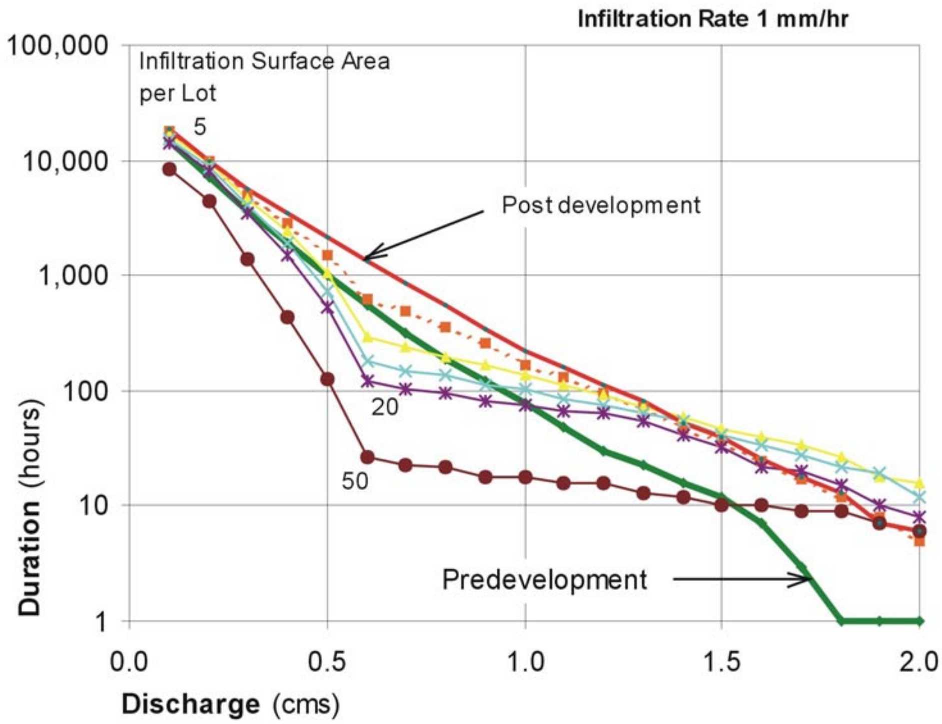

Figure 7. Modified System Operation.

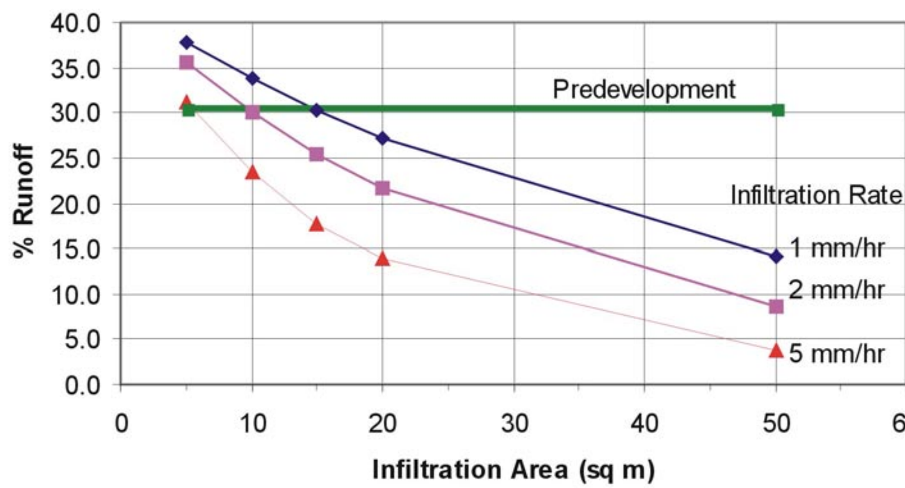

Figure 8. Modified System Runoff Coefficient.

Given the space requirements of both the infiltration system and the offsite servicing for telephone, electricity, cable, water, sanitary sewer and the storm sewer there is little space left for the infiltration systems. The largest practical system would be approximately 15 m^2 in area and must be located beneath the driveway. This limits the effectiveness and expandability of the infiltration systems.

Conclusions

The infiltration capacities available in the Development Area are quite low; ranging from 0 mm/hr to 2.8 mm/hr. These low infiltration rates present a challenge for the use of infiltration systems to meet the provincial objectives to have the post development hydrology to mimic the predevelopment hydrology. The proposed design will allow the duration of discharge to closely match the predevelopment values, however the durations for post development will not precisely match the predevelopment values.

The systems as analysed can meet the objective of reducing the volumetric runoff coefficient to predevelopment values however the storage utilization and discharge duration present a problem that was addressed by incorporating a small (10 mm) hole in the system overflow. The systems also require nearly twice the volume of storage as would be considered using a single event design storm methodology.